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A COMPARISON BETWEEN INFRARED SATELLITE IMAGES AND SEA TRUTH MEASUREMENTS

L. Prieur and J.P. Bethoux
Laboratoire de Physique et Chimie Marines
Villefranche sur mer

M. Albuisson, L. Wald and J.M. Monget
Ecole Nationale Supérieure
Sophia Antipolis, FRANCE

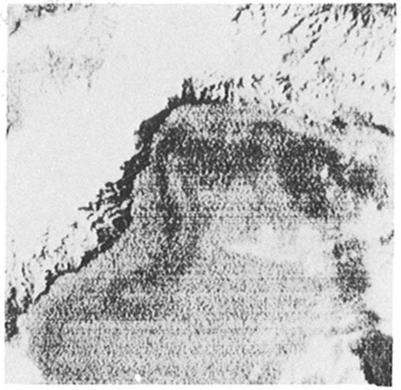
1. ABSTRACT

A method for processing NOAA-VHRR and TIROS N-VHRR data is outlined. Noise elimination is performed and sea surface temperature maps are produced with a maximum temperature resolution of 0.5° C. A comparison is shown between in situ temperature measurements and VHRR radiometric temperatures along a track intersecting the cyclonic gyre of the Liguro-Provencal basin. The ecologic significance of the observed thermal fronts is demonstrated by stations showing the vertical variations of oceanographic parameters. The satellite image allows apprehension of the two dimensional geometry of these fronts. This information can be used in the evaluation of the primary production of the basin. It is also emphasized that the systematic processing of I.R. images brings a significant contribution to the planning of future oceanographic cruises.

2. SATELLITE DATA

Since 1972, NASA has regularly launched a series of meteorological satellites which are under supervision of NOAA. The NOAA satellites (currently TIROS N) are equipped with various electro optical systems. Among them the system of interest is the VHRR which operates in the spectral band from 10.5μ to 12μ. Two types of disturbances have been identified on the raw data (Fig. 1) and have to be minimized before interpreting the images for oceanographic applications:

- a background noise caused by transmission, or analog to digital conversion;



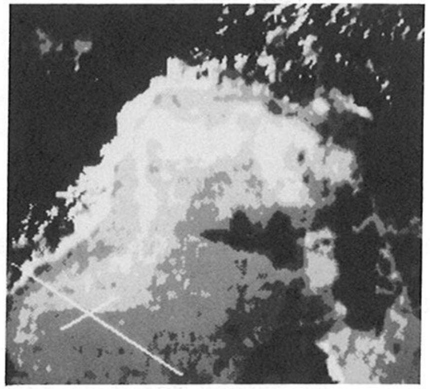


Fig. 1 (left): untreated image of the Liguro-Provencal basin from VHRR-NOAA 5 on 9 March 1978. The French and Italian Riviera coasts are visible. Cape of Corsica is seen black in the lower right.

Fig. 2 (right): The same image as Fig. 1 but smoothed and in negative. Clouds over sea are in black. Ship-tracks are drawn in white. From black to white, each shade difference corresponds to an increase in temperature of 0.5° C.

- a striping effect due to sensor gain losses affecting the calibration signals during data acquisition.

The striping effect is minimized by a method which takes into account the complete structure of the marginal distribution of each scan line instead of using only condensed, extracted information such as an average or mode value.

The so called background noise is essentially isotropic in nature, and evenly distributed in the image plane. It is responsible for the "salt and pepper" aspect of the display. Its elimination involves a straightforward two-dimensional weighted smoothing algorithm (Rosenfeld, 1969).

The cleaning effect is satisfactory, especially when the algorithm is iterated several times, leading to a contouring effect in the display which is useful for oceanographic applications. The disadvantage of this approach is that the contrast at the boundary between the earth and the sea is smeared at each iteration with a consequent degradation for the geographic location of the coastlines. This annoying effect is of particular importance for coastal applications, where it is desirable to retain the original spatial definition of the coastline as produced by the ground resolution of the

NOAA scanner data (approximately 1 km). In order to meet this goal, the smoothing was applied only if the local gradient was in the same order of magnitude as the RMS of the background noise. Once the striping and salt and pepper effects are eliminated, the final image (Fig. 2) shows a contrasted temperature field which can be interpreted by oceanographers.

3. COMPARISON WITH SHIP DATA

A comparison is shown between in situ temperature measurements on 7 to 9 March 1978 along the track going from Nice to Calvi (Corsica) and VHRR radiometric temperature taken from NOAA 5 on 9 March 1978. The processed IR satellite images are usable even in the low thermal contrast conditions observed in the springtime across the Liguro-Provencal basin where the thermal discontinuities are often less than 0.5^{o} C. Correlated with in situ observations, these images are helpful in mapping the water masses and determining their origin.

On Fig. 2 the shiptrack of the 7 March 1978 Nice-Calvi cruise is drawn across the cyclonic gyre of the basin. Along this 60 km long track, oceanographic parameters were measured at a depth of 3 meters: temperature T, Chlorophyll concentration Chla, nitrate NO3, and the total scattering coefficient b (Fig. 3). An SST profile taken from the satellite image is displayed as a dashed line on Figure 3 after an arbitrary absolute calibration. Similar data were collected on 8 March along another track represented by the shorter

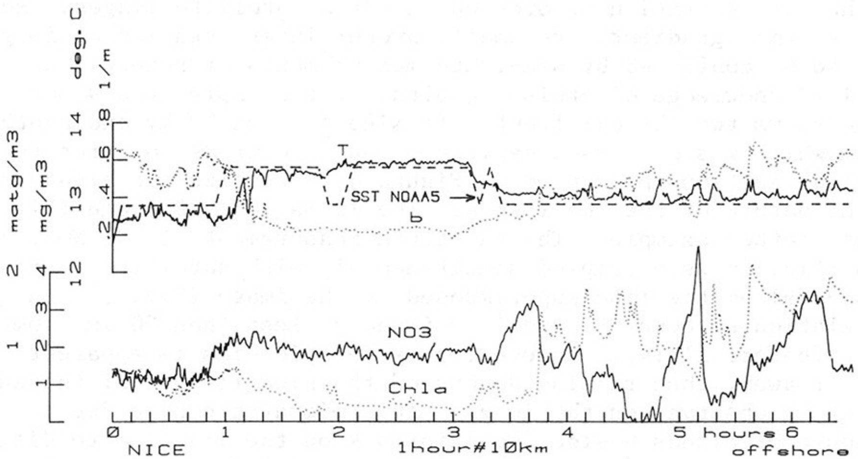


Fig. 3: Ship data of 7 March 1978 for pigments (Chla, $mg.m^{-3}$), nitrate (NO_3, $matg.m^{-3}$), temperature (T, deg. C) and total scattering coefficient (b, m^{-1}) at the depth of 3 m, along the longer track on Fig. 2.

line in Figure 2. Also, six hydrographic stations were taken on 9 March between Nice and Calvi. All these observations have confirmed the permanent nature of the thermal structure noticed during the 7 March cruise and the consistency between sea-truth and satellite measurements taken two days apart.

The relatively warm water encountered during part of the ship-track is related to a coastal system with low values of turbidity (b), phytoplankton, and nutrients. This tongue-like structure (Fig. 2) can be followed up to the coast of Genova and the Tyrrhenian sea in the satellite image, and is markedly different from the central part of the cyclonic gyre characterized by higher values in NO3 and Chla, thus indicating a patchlike springtime primary production. The thermal front at 30 km separating the two water masses is easily identified in the IR satellite image and its global geographic position has been confirmed by the French and Italian cruises in March 1979 and 1980. This front is characterized by a convergence zone between stations 11 and 12 (Fig. 4) as one can see from the vertical distribution of parameters b, chla, T, S, seston weight and NO3. This convergence is related to a neighbouring upwelling of nutrient rich deep water. It can be deduced from this vertical section that the primary production is increased near the front despite the downward entrainment of biomass.

4. INTERPRETATION AND USE OF SATELLITE IMAGERY

The persistence and stability of such a front, associated in springtime with an important primary production, have been confirmed by the interpretation of over one hundred satellite images. However, when thermal gradients are small, proper interpretation of images have to be confirmed by sea-truth measurements or referred to a detailed knowledge of cruise results. For example, the 9 March 1978 image shows two thermal fronts off Nice (one at 10 km and another at 30 km which was discussed earlier). But one needs to refer to the vertical sections presented in Figure 4 to realize the highly different nature of the two fronts. The 12 March 1979 image (Fig. 5) shows another example. The sea-truth measurements T, S, NO3, b, Chla (Fig. 6) were sampled simultaneously with satellite overpass (14h59) along the line superimposed on the image (Fig. 5). A good correlation between SST and T is found at less than 20 km from the coast (before 11h14). However, a systematic bias is apparent farther away, thus raising doubts on the significance of the surface structure observed on the image. This mismatch can be due to the presence of clouds beside the shiptrack on the image or to different meteorological conditions along the track (wind was always less than 4 knots, but the sky over the ship was cloudy at 9 am and clear at 1 pm).

Despite these limitations to the reliability of interpretation of individual images, the systematic analysis of times sequences of

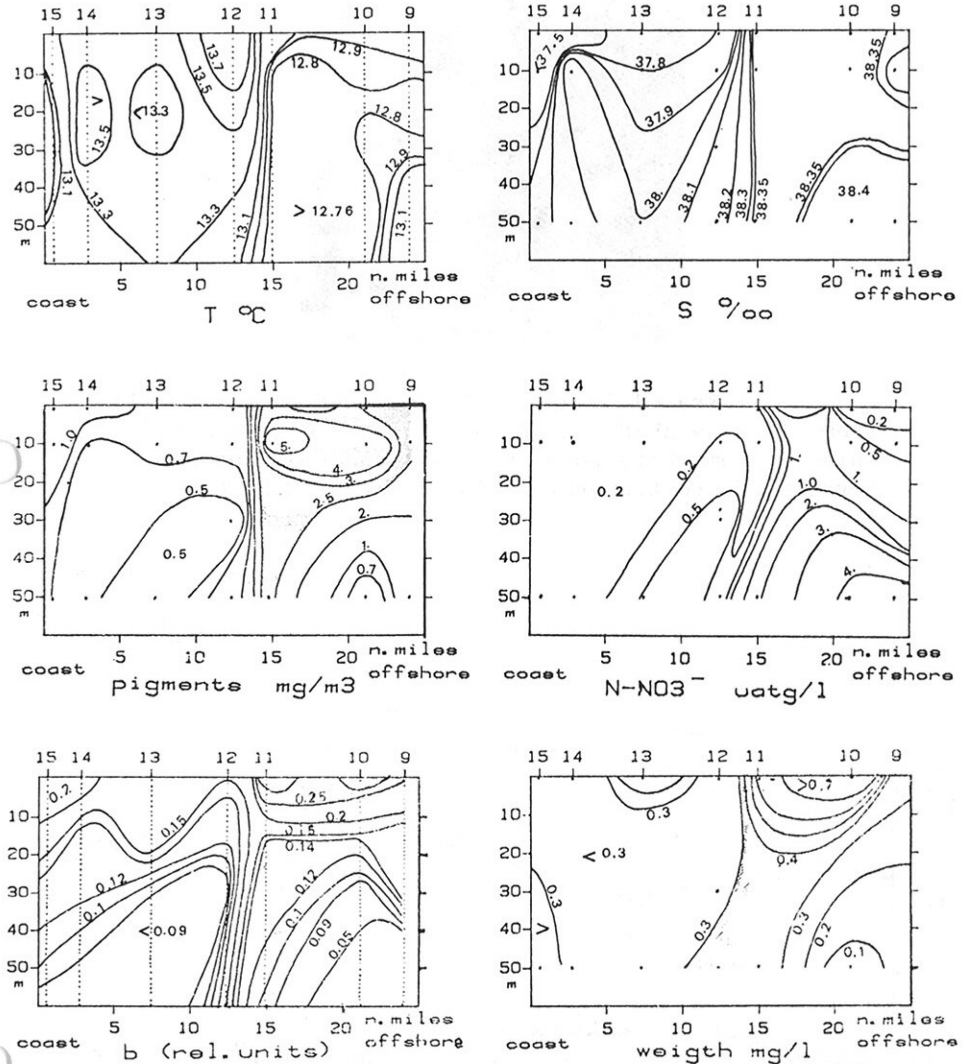


Fig. 4: Vertical distribution of each parameter, temperature, salinity, total scattering coefficient, pigments (in terms of chlorophyll a), nitrate and dry seston weight on 9 March 1978 along the same track as in Fig. 3. The station numbers are indicated in the upper part of the figure. For T and b, continuous data were available from 0 to 60 m. There is a thermal front and a convergence between stations 11 and 12. Production is high near this front, whereas it is low near the thermal front between stations 14 and 15.

Fig. 5: Infrared image of the Liguro-Provencal basin from TIROS N-AVHRR on 12 March 1979. Clouds are in white. From white to black, each shade difference corresponds to temperature increment of 0.2° C.

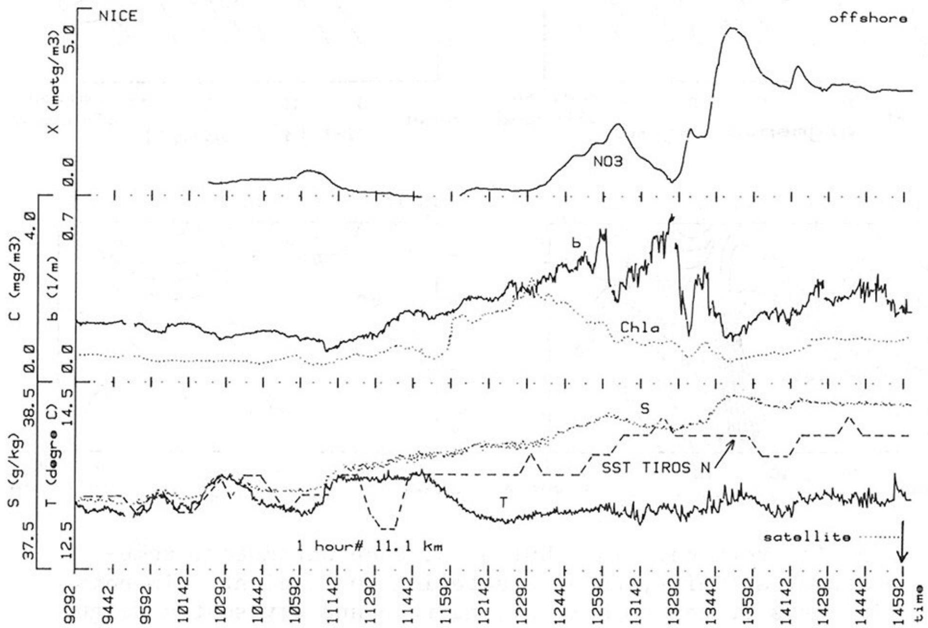


Fig. 6: Ship data of 12 March 1979 along the track indicated in Fig. 5. X-axis is graduated in local time (GMT + 1) of data acquisition. The satellite passage time was 2.59 pm. The higher phytoplankton biomass (chla) was observed in the zone limited by the thermal front (11h59) and the salinity (S) and nitrate front (13h44). But the thermal front is not visible on satellite data (see text).

IR images over a geographical area leads to the determination of permanent structures at a scale of tens of kilometers within the region. This approach was used in order to study the thermal signature of the Liguro-Provencal cyclonic gyre at various periods of the year and to outline the influence of dominant winds on this system (Wald, 1980).

Such a systematic analysis also helps orient some studies of the sea. Some small scale thermal structures of a few kilometers, superimposed on the general circulation, have been observed on several satellite images. The fact that these structures are present on several successive images (Figs. 7 and 8) seems to indicate their oceanic nature. Therefore, although the PROLIG cruise was carried out at a different period of year, a part of this cruise was devoted to the mapping of fronts and other structures of small size. In order to fulfil this goal, a series of 15 nautical mile legs were drawn 2.5 miles apart. The high variability of the hydrological structure was then observed in March in the region 15 miles off Nice. This phenomenon is related to complex horizontal and vertical movements near the front separating coastal waters from offshore waters. These movements strongly affect the phytoplankton distribution at the surface. This distribution is shown in Figure 9 through the intermediary of the scattering coefficient,

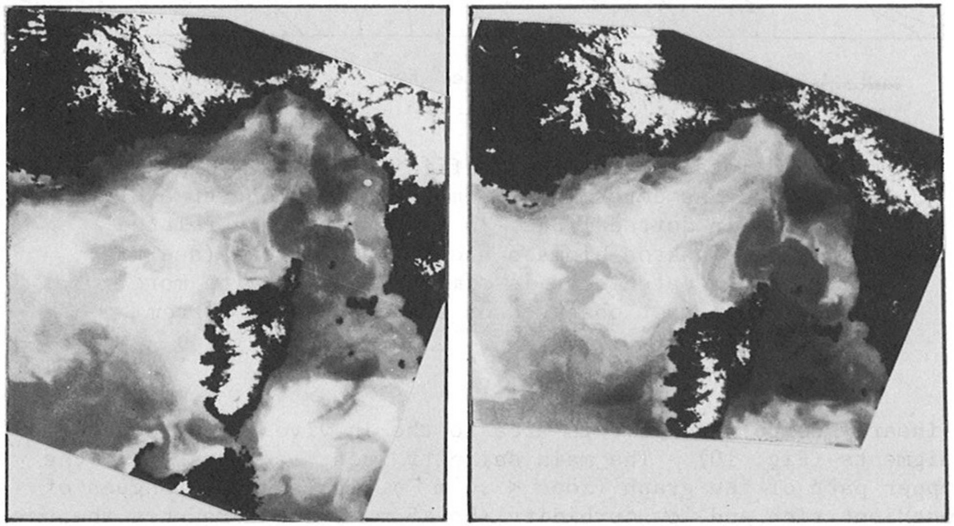


Fig. 7 (left): TIROS N-AVHRR image of the Liguro-Provencal basin showing the complex thermal structure of the surface when mapped at each 0.2° C interval. 31 August 1979 14h02 GMT.

Fig. 8 (right): The same as Fig. 7, the next day. The same thermal structure is observed. 1 Sept. 1979 13h50 GMT.

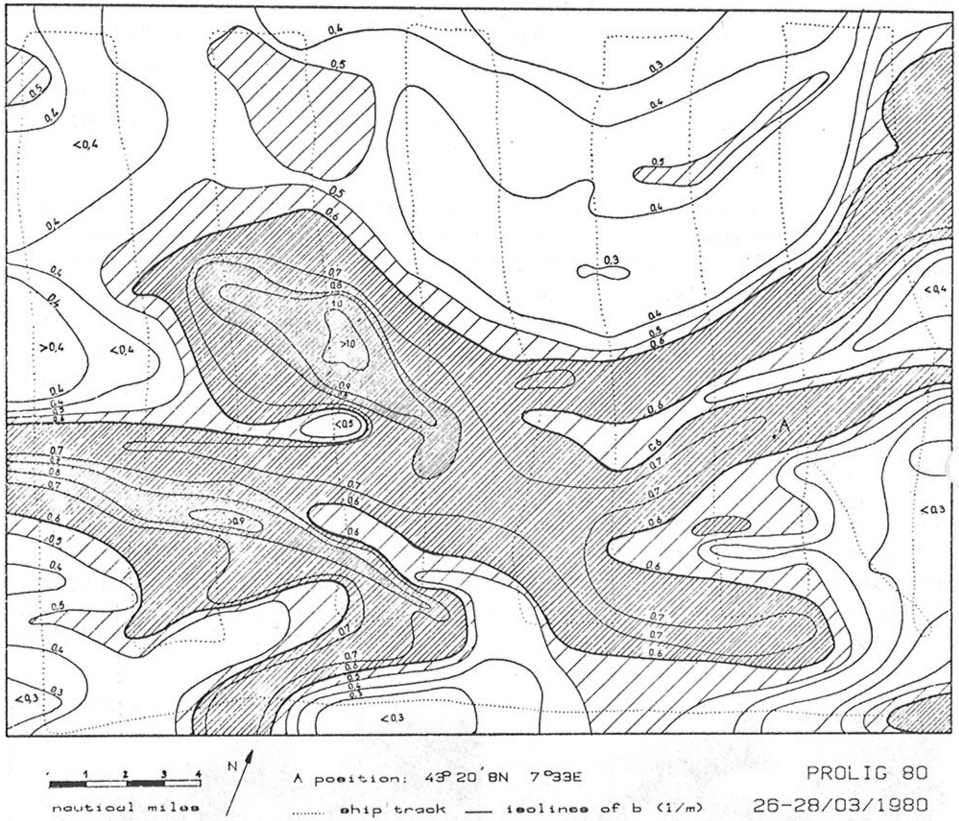


Fig. 9: Total scattering coefficient (b) field at the surface as determined from the ship along tracks indicated in dotted lines. b is very closely related to a phytoplankton biomass along these tracks (see Fig. 10). Such a patchiness is similar to, but with more details than that observed on temperature maps from satellite data.

linearly correlated in this area to the in vivo fluorescence of pigments (Fig. 10). The main salinity front is situated in the upper part of the graph (zone < .4 m^{-1}), while three tongues of nutrient rich and low turbidity (b< .5 m^{-1}) water reaches the surface in the bottom of the graph. In the center the phytoplankton biomass is higher (b< .6) particularly near an incursion of less salty and clearer water which may be of coastal origin.

Despite the limits in interpretation due to atmospheric phenomena and sea state, the sea surface temperature images have definitely proved useful in mapping water masses. They also helped in the planning of the spatial distribution of hydrographic measurements.

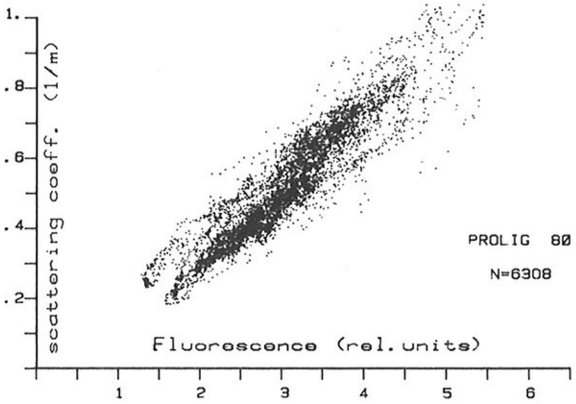


Fig. 10: Scatter diagram of b versus in vivo fluorescence of phytoplankton corresponding to the tracks of 25-28 March 1980.

5. ACKNOWLEDGEMENTS

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